US-PAT-NO: 5553076

DOCUMENT-IDENTIFIER: US 5553076 A

TITLE: Method and apparatus for a wireless local area network

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Detailed Description Text - DETX (4):

Referring to FIG. 2, there is shown a schematic block level diagram of a wireless terminal 30. In general, the wireless terminal 30 comprises an RF/IF unit 24, an Analog Front End (AFE) 26, a Baseband Modem 28, an FEC Codec 29, and a Protocol & Control Unit (PCU) 80, whose components will be described in greater detail hereinafter.

Detailed Description Text - DETX (6):

The AFE 26 provides the digital-to-analog and analog-to-digital conversion between the RF/IF Unit 24 and the Baseband Modem 28. In addition, AFE unit 26 performs associated anti-aliasing and reconstruction filtering. The digital-to-analog and analog-to-digital conversions are provided for both in-phase and quadrature-phase signals, each of which must be sampled at twice the PN code chip rate.

Detailed Description Text - DETX (7):

The Baseband Modem 28 provides the functions of spreading and de-spreading, PN code generation, acquisition and synchronization, combining and message buffering. The Baseband Modem 28 handles many signal processing functions including the control of the RF/IF unit 24 and control logic for the modem blocks.

Detailed Description Text - DETX (9):

The PCU 80 implements the protocol of the communication which is the method of the present invention, controls the Baseband Modem 28, implements the power saving feature of the present invention, handles messages, and interfaces to the Network Interface Controller (NIC) for the higher protocol layers.

Detailed Description Text - DETX (19):

Thus, from FIG. 2, it can be seen that the RF/IF unit 24 comprises amplifier 112, multiplier 110, filter 108, variable attenuator 106, I/Q modulator 104, low noise amplifier 40, mixer 42, second filter

46, second amplifier 48, I/Q demodulator 52, multiplier 54, temperature compensated crystal oscillator 50, frequency synthesizer 44, and the transmit/receive (T/R) switch 38. The Analog From End (AFE) 26 comprises filters 102(a-b), D-to-A converter 98, filters 56 (a-b), and A-to-D converter 58. The Baseband Modem 28 comprises I/Q spread unit 96, differential encoder 94, transmit block 90, RF/IF control unit 36, PN generator 62, Steady State (SS) sync unit 82, Pseudo Noise Match Filter (PNMF) 60, adaptive combiner 64, sync acquisition block 74, differential decoder 66, detect logic unit 76, received block 70, and control logic unit 72. The FEC Codec 29 comprises the FEC decoder 68, and the FEC encoder 92. Finally, the wireless terminal 30 comprises the Unit (PCU) 80.

Detailed Description Text - DETX (22):

Referring to FIG. 4, there is shown one embodiment of a base stationary unit 20. The base stationary unit 20 is very similar to the wireless terminal 30. In block diagram form, the base stationary unit 20 comprises the two antennas 32a and 32b connected to a switch 34 which is controlled by an RF/IF control unit 36. The two antennas 32a and 32b perform the same functions as the two antennas for the wireless terminal 30. The signals to and from the antennas 32(a-b) are supplied by the RF/IF unit 24, which is the same as that described for the wireless terminal 30. The RF/IF unit 24 is connected to the AFE unit 26, which is also the same as that described for the wireless terminal 30. A baseband modem 128 is also connected to the AFE unit 26. The baseband modem 128 is similar to the baseband modem 28, except for the absence of the sync acquisition block 74 and the detect logic 76. In all other aspects, the baseband modem 128 is similar to the baseband modem 28. The FEC Codec 29 is similar to the FEC Codec shown and described for the wireless terminal 30. Finally, the PCU 80 is also similar to the PCU 80 shown and described for the PCU 80 of the wireless terminal 30.

Detailed Description Text - DETX (28):

The SYNC signal transmitted by the base unit 20 is received by each of the wireless terminals 30 within the data cell 10 to the extent that the wireless terminal 30 can so receive (the limitation being interference, etc.). If the wireless terminal 30 received the SYNC signal, then it is used as a clocking signal for the wireless terminal 30. This occurs through the action of the sync acquisition unit 74 through the logic detect unit 76 to the CLU 72. Furthermore, once the status signal is received and is decoded to be Idle by the CLU 72 of each wireless terminal 30, if the wireless terminal 30 does not request transmission (to be discussed hereinafter), then through the circuit shown in FIG. 3, the CLU 72 would power down the transmitter section and the receiver section of the wireless terminal 30, thereby saving power.

US-PAT-NO: 5910970

DOCUMENT-IDENTIFIER: US 5910970 A

TITLE: MDSL host interface requirement specification

Abstract Text - ABTX (1):

A modem that operates selectively in the voice-band frequency band and higher frequency bands is provided. This modem supports multiple line codes, like DMT and CAP. The modem uses a Digital Signal Processor (DSP), so that different existing ADSL line codes, such as Discrete MultiTone (DMT) and Carrierless AM/PM (CAP), can be implemented on the same hardware platform. The modem employs a method for interfacing the modem hardware with a host operating system. The method calls a defined set of host interface functions for command/control, calls a defined set of host interface functions for link correction management, calls a defined set of host interface functions for data sending/receiving, calls a defined set of host interface functions for synchronization between voice-band audio and above voice-band audio, and calls a defined set of host interface functions to use the voice-band as control channel and above voice-band as a data channel.

Brief Summary Text - BSTX (4):

A conventional voice-band modem can connect computer users end-to-end through the Public Switched Telephone Network (PSTN). However, the transmission throughput of a voice-band modem is limited to below about 40 Kbps due to the 3.5 KHz bandwidth enforced by bandpass filters and codes at the PSTN interface points. On the other hand the twisted-pair telephone subscriber loop of a computer user has a much wider usable bandwidth. Depending on the length of the subscriber loop, the bandwidth at a loss of 50 dB can be as wide as 1 MHz. Transmission systems based on the local subscriber loops are generally called Digital Subscriber Lines (DSL).

Brief Summary Text - BSTX (5):

As consumer demand for interactive electronic access to entertainment (e.g. video-on-demand) and information (Internet) in digital format has increased, this demand has effectively exceeded the capabilities of conventional voice-band modems. In response, various delivery approaches have been proposed, such as optical fiber links to every home, direct satellite transmission, and wideband coaxial cable. However, these approaches are often too costly, and cheaper alternatives have emerged, such as the cable modem which uses existing coaxial cable connections to homes and various high bit rate

digital subscriber line (DSL) modems which use the existing twisted-pair of copper wires connecting a home to the telephone company central office (CO).

Brief Summary Text - BSTX (7):

An example of prior art use of DSL techniques is the Asymmetrical Digital Subscriber Line (ADSL) signaling for the telephone loop that has been defined by standards bodies as a communication system specification that provides a low-rate data stream from the residence to the CO (upstream), and a high-rate data stream from the CO to the residence (downstream). The ADSL standard provides for operation without affecting conventional voice telephone communications, eg. plain old telephone service (POTS). The ADSL upstream channel only provides simple control functions or low-rate data transfers. The high-rate downstream channel provides a much higher throughput. This asymmetrical information flow is desirable for applications such as video-on-demand (VOD).

Brief Summary Text - BSTX (8):

ADSL modems are typically installed in pairs, with one of the modems installed in a home and the other in the telephone company's central office servicing that home. The pair of ADSL modems are connected to the opposite ends of the same twisted-pair and each modem can only communicate with the modem at the other end of the twisted-pair; the central office will have a direct connection from its ADSL modem to the service provided (e.g., movies, Internet, etc.). FIG. 2a heuristically illustrates an ADSL modem (FIG. 2a uses "DSL" rather than "ADSL" for the modem) installed in the central office and one in the consumer's home, either a personal computer or a TV set-top box. Because an ADSL modem operates at frequencies higher than the voice-band frequencies, an ADSL modem may operate simultaneously with a voice-band modem or a telephone conversation.

Brief Summary Text - BSTX (9):

A typical ADSL-based system includes a server located at the CO capable of providing movies or other data-intensive content, and a set-top-box at the residence that can receive and reassemble the data as well as send control information back to the CO. Meaningful display or use of the downstream content typically requires a sustained data rate through the modem. Due to the sustained data rate requirements, ADSL systems are primarily designed to function under certain operating conditions and only at certain rates. If a subscriber line meets the quality requirements, the ADSL modem can function, otherwise new line equipment must be installed, or line quality must be improved.

Brief Summary Text - BSTX (10):

In particular, the ANSI standard ADSL calls for transmission of up to 6 million bits-per-second (Mbps) to a home (downstream) over existing twisted-pair and also for receipt of up to 640 thousand bits per second (Kbps) from the home (upstream).

Brief Summary Text - BSTX (11):

An ADSL modem differs in several respects from the voice-band modems currently being used for digital communication over the telephone system. A voice-band modem in a home essentially converts digital bits to modulated tones in the voice-band (30 Hz to 3.3 KHz), and thus the signals can be transmitted as though they were just ordinary speech signals generated in a telephone set. The voice-band modem in the receiving home then recovers the digital bits from the received signal. The current ITU V-series voice-band modem standards (e.g. V.32 and V.34) call for transmission at bit rates of up to 33.6 Kbps; even these rates are far too slow for real-time video and too slow for Internet graphics. In contrast, an ADSL modem operates in a frequency range that is higher than the voice-band; this permits higher data rates. However, the twisted-pair subscriber line has distortion and losses which increase with frequency and line length; thus the ADSL standard data rate is determined by a maximum achievable rate for a length of subscriber lines, e.g. 9,000 feet (9 kft) for 26 gauge lines, or 12 kft for 24 gauge lines.

Brief Summary Text - BSTX (12):

Voice-band modem data speeds are limited by at least the following factors: 1) the sampling rate of the line cards in the central office is only 8 KHz; 2) the low bit resolution of the A/D and D/A converters used on the line cards reduces dynamic range; and 3) the length of the subscriber line (twisted-pair) and any associated electrical impairments. Although an ADSL modem avoids the first two factors, it also suffers from subscriber line length limitations and electrical impairments. FIG. 4c illustrates how the capacity of a subscriber line decreases with increasing line length for the two existing wire sizes. A similar capacity decrease with length applies to any type of twisted-pair subscriber line modem.

Brief Summary Text - BSTX (13):

FIG. 4ashows in block format a simple ADSL modem whose transmit hardware 30 includes the bit encoder 36, inverse fast Fourier transform 38, P/S 40, digital-to-analog converter 42, filter and line driver 44 for transmission and transformer 46. The receive portion 32 includes a transformer and filter 48, analog-to-digital converter 50, an equalizer for line distortion compensation 52, S/P 54, fast

Fourier transform 56, and bit decoder 58. An echo cancellation circuit from the transmission portion to the reception portion may be included to suppress signal leakage. The ADSL standard uses discrete multitone (DMT) with the DMT spectrum divided into 256 4-KHz carrier bands and a quadrature amplitude modulation (QAM) type of constellation is used to load a variable number of bits onto each carrier band independently of the other carrier bands.

Brief Summary Text - BSTX (14):

The number of bits per carrier is determined during a training period when a test signal is transmitted through the subscriber line to the receiving modem. Based on the measured signal-to-noise ratio of the received signal, the receiving modem determines the optimal bit allocation, placing more bits on the more robust carrier bands, and returns that information back to the transmitting modem.

Brief Summary Text - BSTX (15):

The modulation of the coded bits is performed very efficiently by using a 512-point inverse fast Fourier transform to convert the frequency domain coded bits into a time domain signal which is put on the twisted-pair by a D/A converter using a sample rate of 2.048 Mhz (4.times.512). The receiving ADSL modem samples the signal and recovers the coded bits with a fast Fourier transform.

Brief Summary Text - BSTX (16):

Discrete multi-tone (DMT) has been chosen as the line code for the ADSL standard. A typical DMT system utilizes a transmitter inverse FFT and a receiver forward FFT. Ideally, the channel frequency distortion can be corrected by a frequency domain equalizer following the receiver FFT. However, the delay spread of the channel in the beginning of the receiver FFT block contains inter-symbol interference from the previous block. As this interference is independent of the current block of data, it can not be canceled just by the frequency domain equalizer. The typical solution adds a block of prefix data in front of the FFT data block on the transmitter side before the block of FFT data is sent to the D/A The prefix data is the repeat copy of the last section of FFT data block.

Brief Summary Text - BSTX (18):

Time domain equalizer training procedures have been studied previously, Equalizer Training Algorithms for Multicarrier Modulation Systems, J. S. Chow, J. M. Cioffi, and J. A. C. Bingham, 1993 International Conference on Communications, pages 761-765, Geneva, (May 1993) and the corresponding training sequence has been specified in ADSL standard and Recommended Training Sequence for Time-domain

Equalizers (TQE) with DMT, J. S. Chow, J. M. Cioffi, and J. A. C. Bingham, ANSI T1E1.4 Committee Contribution number 93-086.

Brief Summary Text - BSTX (19):

The following patents are related to DMT modems: U.S. Pat. No. 5,400,322 relates to bit allocation in the multicarrier channels; U.S. Pat. No. 5,479,447 relates to bandwidth optimization; U.S. Pat. No. 5,317,596 relates to echo cancellation; and U.S. Pat. No. 5,285,474 relates to equalizers.

Brief Summary Text - BSTX (20):

Alternative DSL modem proposals use line codes other than DMT, such as QAM, PAM, and carrierless AM/PM (CAP). Indeed, ISDN uses a 2bit-1quaternary (2B1Q) four level symbol amplitude modulation of a carrier of 160 KHz or higher to provide more data channels.

Brief Summary Text - BSTX (21):

CAP line codes typically use in-phase and quadrature multilevel signals which are filtered by orthogonal passband filters and then converted to analog for transmission. FIG. 4b shows a block diagram for the transmitter 321 and receiver 325 of a DSL modem using the CAP line code and including both an equalizer 750 and echo cancellation 327.

Brief Summary Text - BSTX (24):

However, these DSL modems have problems including: 1) higher bit rates for video that cause them to be complicated and expensive; 2) their bit rates are optimized for a fixed distance, making them inefficient for short subscriber loops and unusable for long subscriber loops; and 3) either DMT or CAP operates better for given different conditions (e.g. noise, etc.) that may or may not be present in a particular subscriber loop to which the DSL modem is connected.

Brief Summary Text - BSTX (27):

The present invention provides a new high speed modem for use on standard telephone twisted-pair lines at lengths of up to 21,000 ft. This new modem will be referred to as MDSL, mid-band digital subscriber line. The MDSL modem of the present invention makes use of frequency division multiplexing (FDM) to separate the downstream and upstream transmitted signals. Although the modulation scheme for MDSL can be arbitrary, two specific modulation schemes that maybe employed are QAM/CAP and Discrete Multitone (DMT). A startup procedure for achieving synchronization between the MDSL modem of the present

invention at the central office (CO) and the MDSL modem at the remote user (RU) end is provided as part of the present invention.

Brief Summary Text - BSTX (29):

The present invention provides a modem which supports both voice-band and above voice-band (DSL) functionality using preselected common circuitry. Preferred embodiments use a DSP to run either voice-band or above-voiced-band modem software in combination with, either separate or combined analog front ends, and a common host interface (either serial or parallel). The same internal components may be employed for either the voice-band or the above-voice-band modem, and the modem may have an integral splitter to separate the voice-band for use by a telephone set.

Brief Summary Text - BSTX (30):

The present invention provides a programmable Digital Signal Processor (DSP) implementation approach that allows different existing ADSL line codes, Discrete MultiTone (DMT) and Carrierless AM/PM (CAP), to be implemented on the same hardware platform as a voice-band modem. With a DSP implementation, the desired transmission rate can also be negotiated in real time to accommodate line condition and service-cost requirements.

Brief Summary Text - BSTX (31):

This line code and rate negotiation process can be implemented at the beginning of each communication session through the exchange of tones between modems at both ends. A four-step Mid-band Digital Su (MDSL) modem ini(MDSL) modem initialization process is used for line code and rate compatibility.

Brief Summary Text - BSTX (32):

Although Digital Subscriber Line (DSL) signaling is used to convey digital data over existing twisted-pair copper telephone lines connecting the telephone company central office (CO) to residential subscribers, conventional DSL data modems are designed to provide service to a certain percentage of residential customers at a prescribed data rate. A new rate negotiation method of the present invention enables a variable-rate DSL (VRDSL) system. Using the rate negotiation method, the variable rate system adapts its throughput based on line conditions, computational capabilities, network accessibility, and application requirements. This service can be added to a telephone subscriber loop without disrupting the plain old telephone service (POTS). Hence, a voice-band modem connection can also be made available independent of the DSL connection.

Brief Summary Text - BSTX (33):

The rate negotiation method provides systematic control for a DSL system that supports multiple rates. The data rates can be varied depending on modem cost, line conditions, or application requirements. The modem functions as a variable rate data link capable of supporting many different applications, including VOD, videophone, multiple ISDN links, and new network access applications. By considering the capability of a particular DSL connection, available computational power, and any special application program requirements, the data rate can be adapted by the negotiation method to a suitable level. This scheme provides symmetrical or asymmetrical data links and supports simultaneous applications requiring arbitrary mixes of symmetrical and asymmetrical links. A part of the symmetrical portion of the DSL transmission throughput can be used for telephone calls or video telephone calls. A part of the asymmetrical portion of the DSL transmission throughput can be used for internet access or VOD services. The rate negotiation method supports many different network applications using DSL.

Brief Summary Text - BSTX (34):

The typical implementations of DSL modems, thus far, have supported only connectionless services between the subscriber and the network. However, since DSL is terminated at the local central office, a telephone-network friendly DSL interface is desirable. To facilitate multiple virtual service connections, an operations/signaling channel, similar to the ISDN D channel, is preferred for exchanging service and control messages. A preprocessor in the CO-end DSL modem is also necessary to collect operational messages before passing signaling and data packets to the CO control channel server.

Brief Summary Text - BSTX (35):

The DSL modem of the present invention supports connectionless as well as connection-oriented (switched) services.

Brief Summary Text - BSTX (36):

The method of rate negotiation is preferably employed with a DSL system capable of a varying rate. An example is a variable-rate DSL (VRDSL) system that can provide a variable upstream transmission throughput up to 400 Kbps and a downstream transmission throughput of from 400 Kbps up to 2.048 Mbps. (However, the invention is not constrained to vary within the rates given by this example system.) With lower throughput, operation with poor line conditions is supported. Lower data rates also allow the design of less expensive modems for less demanding applications. This is consistent with the

mid-band DSL (MDSL) design philosophy of the present invention, which can provide a symmetrical 400 Kbps link using the same hardware platform as a voice-band modem. With high downstream throughput, VRDSL can be made compatible with ADSL. Basically, the VRDSL rate negotiation method provides the capability to serve a range of price/performance DSL modems that can maximize throughput based on individual line conditions and processing power. In VRDSL signaling, the POTS will still be available through the same telephone subscriber loop.

Brief Summary Text - BSTX (39):

The line connection management process for a mid-band digital subscriber lines (MDSL) provides a simple, efficient and flexible interface to manage the line connection between MDSL-C (MDSL in Central Office site) and MDSL-R (MDSL in residential site). MDSL uses four different line modes: leased line with single link (LLSL); leased line with multiple links (LLML); switched line with soft dial (SLSD); and switched line with hard dial (SLHD). The host interface for the LLSL mode, has three different line states: line drop, line disconnected and line connected. An internal state machine of the MDSL modem can record and monitor the line status and notify the state change to the other MDSL modem, as well as the host processor. The protocol used for exchanging line connection management messages of the present invention is a simplified point-to-point link control protocol.

Brief Summary Text - BSTX (42):

The present invention also provides a simple algorithm to train the time domain equalizer of an MDSL modem. By the same procedure, the FFT frame boundary is also reliably detected.

Drawing Description Text - DRTX (3):

FIGS. 1a-e show a preferred embodiment multimode modem.

Drawing Description Text - DRTX (4):

FIGS. 2a-c show preferred embodiment modem Central Office modems;

Drawing Description Text - DRTX (5):

FIGS. 3a-e show preferred embodiment modem applications and ISDN signaling;

Drawing Description Text - DRTX (7):

FIGS. 5a-b show another preferred embodiment modem;

Drawing Description Text - DRTX (13):

FIGS. 11a-n show preferred embodiment modem driver;

Drawing Description Text - DRTX (16):

FIGS. 14a-e show preferred embodiment modem pool.

Detailed Description Text - DETX (3):

FIG. 1a shows a functional block diagram of a first preferred embodiment of a multimode modem 100 of the present invention. In FIG. 1a, modem 100 includes both a voice-band and DSL band data path to a single subscriber line (twisted-pair) 140, which connects to a telephone company central office. A voice-band analog front end (VB AFE) 110 transmits and receives at frequencies in the voice-band (30 Hz to 3.3 Khz), whereas the digital subscriber line analog front end (DSL AFE) 120 transmits and receives at frequencies above the voice-band (above 4 KHz). A Splitter 130 connects to the subscriber line 140 and separates the incoming signals into its voice-band and above-voice-band components. POTS (plain old telephone service) occurs in the voice-band and a telephone may be connected to the subscriber line directly or through the splitter 130.

Detailed Description Text - DETX (4):

Modem 100 utilizes a single programmable digital signal processor (DSP) 150 as part of the DSL band data path and as part of the voice-band data path, but typically uses two separate data input ports. Generally, the DSL band will have a much higher bit rate than the voice-band data path, so using separate DSP ports will be more convenient than using a single port with a buffered multiplexer; although the use of such a multiplexer is an alternative clearly within the scope of the present invention. For example, the DSL band operation modem 100 may employ an upstream (from residence to central office) frequency band centered at 100 KHz with a total bandwidth of slightly less than 200 KHz, and a downstream (from central office to residence) frequency band centered at 300 KHz and also of total bandwidth slightly less than 200 KHz; this frequency allocation provides for full duplex operation of modem 100. Generally multiple DSPs, instead of a single DSP, may be employed to increase functions performed or to increase performance. The DSP 150 is connected to a host interface circuit 160.

Detailed Description Text - DETX (5):

Modem 100 can select from multiple line codes and, further, modem 100 can perform as either a high-bit-rate DSL modem in frequencies above voice-band or as a voice-band modem (such as V.34), either

simultaneously or consecutively, just by switching programs being executed by the DSP 150. The various line code programs can be stored in the DSP onboard memory or in auxiliary memory not shown in FIG. 1a. Also, alternative line codes for the DSL modem operations (e.g., a CAP or a DMT line code) can be used, again depending upon the program executed by the DSP 150.

Detailed Description Text - DETX (6):

FIGS. 1b-c illustrates the DSL data path portion of modem 100 which includes analog-to-digital 172 and digital-to-analog 170 converters, filters 174, 176, a transmission driver 178, and a receiver amplifier 180. FIG. 1b additionally explicitly shows a phase locked loop 182 clock generator that synchronizes the modems' internal clocks with the clock signals from the host (or the central office). FIG. 1c omits the bandpass filters and instead shows 15 various optional memory types, both SRAM 184 and nonvolatile EEPROM 186 which could hold line code programs. When modem 100 acts as a voice-band modem, the splitter 130 provides the voice-band frequencies to the voice-band analog front end 120.

Detailed Description Text - DETX (7):

FIG. 1d illustrates the DSP software for modem 100 in DSL mode and includes (i) an optional kernel (operating system) 190 for the DSP, (ii) host interface 192, (iii) optional management maintenance control 194, (iv) framing 196, (v) embedded operations control 198, (vi) channel multiplexer 199 for multiplexing the embedded operations control with the data stream, (vii) scrambler logic 191 for bitstream scrambling (viii) the transceiver logic 193 such as a CAP or DMT logic which includes the bits-to-symbols conversions, equalization, echo cancellation, and (ix) modulator/demodulator 195 logic and optional forward error correction (FEC).

Detailed Description Text - DETX (8):

FIG. 1e illustrates the software protocol hierarchy for applications running on modem 100 interfacing with a host. The physical layer 185 (layer 1) includes the DSP software for modulation, bitstream scrambling, and multiplexing control signals with the data stream. The data link layer 187 (layer 2) in the DSP includes embedded operations control and framing. The network layer 189 (layer 3) in the host includes the modem driver (e.g. NDIS type for a Windows 95/NT) and transport protocols such as PPP (point-to-point protocol). Applications such as Internet browsers interact with the transport protocols.

Detailed Description Text - DETX (9):

For voice-band modes of operation, modem 100 may use software similar to standard voice-band modems (e.g. V.34, etc.).

Detailed Description Text - DETX (10):

The present invention provides a new high speed modem 100 for use on standard telephone twisted-pair lines at lengths up to 21,000 ft. This new modem 100 will be referred to as MDSL, mid-band digital subscriber line. The MDSL modem 100 makes use of frequency division multiplexing (FDM) to separate the downstream and upstream transmitted signals. Although the modulation scheme for MDSL can be arbitrary, two specific modulation schemes that may be employed are QAM/CAP and Discrete Multitone (DMT). A startup procedure for achieving synchronization between the modem at the central office (CO) and the modem at the remote user (RU) end is provided as part of the invention.

Detailed Description Text - DETX (11):

One of the modulation schemes selected for one embodiment of the MDSL modem is Carrierless AM/PM (CAP). CAP can be considered as a special case of the more conventional Quadrature Amplitude Modulation (QAM). The main difference is that CAP performs most of its processing in the passband, while QAM performs most of its processing at baseband.

Detailed Description Text - DETX (13):

One embodiment uses Carrierless AM/PM (CAP) Modulation and Discrete Multiple-Tone Modulation on the same DSP platform to achieve 16 Kbps-384 Kbps upstream speed (from MDSL-R to MDSL-C) and 384 Kbps-2.048 Mbps downstream speed (from MDSL-C to MDSL-R). The MDSL-C can also be installed as a gateway or router to allow the MDSL-R access to local area networks. Examples of the application of MDSL are described later herein.

Detailed Description Text - DETX (15):

FIG. 2a shows modem 100 in a home 210 communicating with another modem 100 in the central office 220. This central office 220 modem 100 may have various capabilities and loads, and the subscriber loop 140 may be in a particular condition, so the modems execute an initialization process to select the line code (CAP, DMT or others), the bit-rate, and train the equalizers. Then the modems begin data communication.

Detailed Description Text - DETX (16):

FIGS. 2b-c illustrate alternative central office connections to

subscriber lines with DSL modems: each subscriber line has a DSL AFE (analog front end) and a digital switch connects an AFE output to a DSL processor, either a DSP similar to the DSP in the residence or a single DSP for multiple AFEs. The central office monitors the AFE outputs and a digital switch assigns an available DSP to communicate with the corresponding residence DSL modem. The central office polls the AFEs to find active modems in the residences. As FIGS. 2b-c show, the central office DSL modem connects to a remote access server on a local area network with packetized information (e.g., Internet) or a wide area network with constant bit rate data which is sent directly across the public switched telephone network trunk lines. The information sent by the residence modem would be identified or signaled via an out of band signaling method (e.g. similar to ISDN Q.931 signaling), rather than an off-hook signal, plus telephone number sent in the voice-band to the analog switching and line cards. FIG. 2c illustrates the major functional blocks of a central office DSL modem (the DSL band is already separated from the voice-band) as an AFE 240, DSP 260, Communications Controller 280 and ARM or RISC processor 290. The modem has a coconstant bit rate tranconstant bit rate transmissions (voice, video conferencing, etc. being to a time division multiplexed (TDM) bus and packetized data (Internet, Intranet, private networks, etc.) being forwarded to a control bus (and then to the trunk lines). FIG. 2c depicts the terminology "xDSL" which may be ADSL or any other type of DSL modem. These various functions could be all performed in a single DSP 260.

Detailed Description Text - DETX (18):

An alternative is for the central office to monitor each subscriber line with a DSL modem in the above-voice-band frequencies and when the line becomes active, an analog switch connects the subscriber line to a DSL modem in the central office. This mimics FIG. 2b except a simpler monitoring and an analog switch replace AFE monitoring and a digital switch. The same approach may also be used in conjunction with the local pedestal to shorten the subscriber line distance from residence DSL modem to the AFE on the central office end (physically located in the remote pedestal).

Detailed Description Text - DETX (19):

FIG. 3a shows a system with modem 100 in a personal computer 310 running Windows 95 (or Windows NT) with standard protocol stacks communicating over a subscriber line 140 with a corresponding modem 100 in the central office 220, which may be connected to an Internet access server via an Ethernet (10/100 Base T) interface. Modem 100 allows for both POTS or voice-band modem communication with another voice-band modem at the same time as the DSL portion of modem 100 connects to the Internet over the DSL portion.

Detailed Description Text - DETX (20):

Similarly, FIG. 3b shows a DSL modem acting as a router 330 for a local area network (LAN) 320 and coupling to devices 340, 342, 344 with corresponding DSL modems.

Detailed Description Text - DETX (21):

FIG. 3c shows half of a teleconferencing system based on modem 100 in a PC 350. Each teleconferencing end has modem 100 communicating at 384+16 Kbps with a modem in a central office 220. The central office modem transmits data between a concentrator and packetizer 360, and the packetizer converts to the 16 Kbps signaling channel into ISDN like signaling messages and applies the 384 Kbps stream to the T1/T3 service across the public switched telephone network. The central office 220 for the receiving party inverts these operations to feed the receiving modem 100. Traffic in the opposite directions proceeds similarly. Note that POTS can simultaneously be used with modems 100 for the voice in the teleconferencing. An analog delay can be inserted in the POTS output to synchronize with the video.

Detailed Description Text - DETX (22):

FIGS. 3d and 3e show ISDN-type signaling protocols and messages; modem 100 sends voice or data over the public switched telephone The SS7 network provides the backbone for carrying the ISDN user's part (ISUP) messages for call set-up and tear-down through the network.

Detailed Description Text - DETX (23):

FIG. 5a shows multimode modem 500, which includes the modem 100 features of both a DSL AFE 110 and a VB AFE 120, with a splitter 130 for subscriber line 140 connection together an ISDN front end 510 for connection to an ISDN line 142 plus an audio front end 520 for driving a speaker 146 and receiving a microphone 144 output as could be used for supporting a hands-free speakerphone. External RAM 530 may be nonvolatile (EEPROM or Flash EPROM) and/or volatile (SRAM or DRAM). The external RAM 530 may contain various programs for different line codes that may be used by the DSP 150. Such line codes may be DMT, QAM, CAP, RSK, FM, AM, PAM, DWMT, etc.

Detailed Description Text - DETX (24):

The transmit part of modem 100 consists of in-phase and quadrature passband digital shaping filters implemented as a portion of QAM transceiver logic; and the receive part consists of a fractionally spaced complex decision feedback equalizer (DFE) with in-phase and quadrature feedforward filters and cross-coupled feedback filters implemented as a portion of QAM transceiver logic. Optionally, the QAM transceiver logic may include a Viterbi decoder.

Detailed Description Text - DETX (25):

When modem 500 is active, modem 500 may provide voice-band modem functionality, DSL band modem functionality, ISDN functionality, audio functionality, other line code functionality, etc., or any combinations of the foregoing.

Detailed Description Text - DETX (29):

Referring now to FIG. 6a, there may be seen a schematic diagram of the interconnection of a telephone 212 and modem 500 to a central office 220, via a subscriber loop 140.

Detailed Description Text - DETX (33):

The transmission throughput of DSL for ISDN Basic Rate Access Channel is 160 Kbps. The transmission throughput of HDSL for repeaterless T1 is 800 Kbps. The transmission throughputs of ADSL are between 16 Kbps to 640 Kbps in the upstream (from a subscriber to a telephone central office) and between 1.544 Mbps to 6.7 Mbps in the downstream. The transmission throughputs of MDSL are presently believed to be 384 Kbps in the upstream and between 384 Kbps to 2.048 Mbps in the downstream.

Detailed Description Text - DETX (35):

More particularly, D/A 614 is connected to transmitter fitters 610, 612 and to filter 616. Filter 616 is connected to channel 620. Channel 620 is connected to filter 630 which is connected to A/D 632. A/D 632 is connected to equalizers 634, 636. A portion of the circuitry 638 recovers the time.

Detailed Description Text - DETX (38):

One MDSL modem embodiment uses frequency division full duplex for lower hardware cost and lower Crosstalk noise level. Such an MDSL modem will provide a minimum of 384 Kbps full duplex transmission link between a central office and a subscriber for a loop length of up to 21 kft. Under favorable subscriber loop conditions, this MDSL modem can provide a much higher transmission throughput which is limited by channel capacity or the hardware capabilities of the subscriber-end modem. A full feature version of a subscriber-end MDSL modem communicates with ADSL modems at the central office end. The transmitter and receiver parts of the MDSL modem are capable of implementing either CAP or DMT line codes.

Detailed Description Text - DETX (39):

FIG. 6e depicts a block diagram of an MDSL modem 600. Modem 600

has a transmitter 676 connected to a D/A 674 which is connected to a filter 672 which is connected to hybrid circuit 670 which is connected to splitter 130. Hybrid circuit is also connected to filter 678 which is connected to A/D 680. A/D 680 is connected to receiver 682 which outputs the received signal. Timing recovery block 684 is used to recover the central office clock timing.

Detailed Description Text - DETX (42):

An MDSL modem at the subscriber-end sends probing tones in the upstream band for a certain duration, with or without phase alternation for a part of these tones, according to a predefined time sequence. After the first time duration, the MDSL modem at the central office end responds with channel probing tones in the downstream band, again, with or without phase alternation for a part of these tones. This initial channel probing period may be repeated, if desired or necessary.

Detailed Description Text - DETX (43):

After the initial channel probing period, the MDSL modem at the subscriber-end has determined the line code capability of the central office end modem and has a channel model for the downstream band and, similarly, the MDSL modem at the central office end has determined the line code capability of the subscriber-end modem and has a channel model for the upstream band.

Detailed Description Text - DETX (44):

After the channel probing period, the MDSL modem at the subscriber end should indicate/confirm its line code capability/preference by sending signature tones for a predefined time duration. Similarly, the MDSL modem at the central office end should respond/confirm the line code selection by sending signature tones for a predefined time duration. This signature tone exchange process is preferably repeated for a limited number of times to determine a particular line code choice.

Detailed Description Text - DETX (45):

Another set of signature tones is then exchanged between MDSL modems at both ends for the transmission rate negotiation. The MDSL modem at the subscriber-end sends its rate capabilities and its preference. The MDSL modem at the central office end responds with its capabilities and its rate selection. MDSL modems determine a rate choice with a predefined rate change procedure described later herein. The transmission rate preference at the subscriber-end depends on the line condition, hardware capability, and user choice or application requirements. The transmission rate preference at the

central office end depends on the line condition and the traffic load. Preferably, rate change during a communication session due to line condition change or user choice is allowed.

Detailed Description Text - DETX (47):

The spectra of upstream and downstream probing tones are depicted in FIG. 6f. The upstream CAP tones 690 and downstream CAP tones 692 are depicted on the left side, while the upstream DMT 694 and downstream DMT 696 are depicted on the right. The "broken" lines in the DMT spectra represent phase shifts.

Detailed Description Text - DETX (71):

If the MDSL service is available through the telephone loop, the MDSL modem at the central office end should be on and monitor the upstream frequency band for probing tones.

Detailed Description Text - DETX (72):

Once power is on or a user service request is made, the MDSL modem at the subscriber-end sends upstream probing tones for a predefined time period and then monitors downstream probing tones. The MDSL modem at the central office end detects the probing tones, compensates for the random phase, stores them, and calculates the upstream channel transmission throughput. Meanwhile, the central office end MDSL modem sends the probing tones in the downstream frequency band.

Detailed Description Text - DETX (73):

The MDSL modem at the subscriber-end detects the probing tones, compensates for the random phase, stores them, and calculates the downstream channel transmission throughput. The subscriber-end MDSL modem then sends signature tones in the upstream band to indicate line code and transmission rate preferences.

Detailed Description Text - DETX (74):

The MDSL modem at the central office end detects the signature tones and responds with signature tones corresponding to its preferred offering. The subscriber-end MDSL modem then sends signature tones to confirm the offering or to request offering modification. The MDSL modems go into a transceiver training period after the confirmation of modem offering.

Detailed Description Text - DETX (76):

DSL systems are traditionally engineered for the worst-case line

condition for which service is to be provided. This approach simplifies the general installation procedure for telephone companies. However, restricting the DSL transmission throughput to that achieved in the worst-case line condition leaves most DSL systems operating well below their potential. The invented method provides a systematic procedure for maximizing the physical transmission throughput of each local loop, enabling most DSL modems to operate at much higher rates than traditionally engineered. In fact, this method enables a majority of DSL modems to achieve a transmission throughputs which are only limited by the capabilities of the modem hardware. The rate negotiation method also provides time-varying adaptation in order to maintain the highest possible throughput as line conditions or network accessibility changes.

Detailed Description Text - DETX (78):

The rate negotiation method considers the dynamic nature of the DSL transmission medium. The DSL is a time varying channel whose capacity may change due to improving/degrading channel conditions. As the channel conditions change, the theoretical maximum throughput also changes. The time-varying nature of the channel characteristics dictates the need for rate negotiation techniques to achieve the most efficient use of the channel over time. This provides the capability for maintaining a DSL connection during periods of difficult channel characteristics by lowering the throughput. This also enables the modem to increase the throughput and make the best use of the connection during periods of favorable channel characteristics. Ideally, the transceivers at each end can monitor the channel and maximize their throughput as conditions vary. A practical transmitter/receiver can be designed that increases or decreases throughput of the physical channel based on the available capacity, the available signal processing resources, and the requirements of the specific applications. Several rate adaptation methods exist (e.g. the standard CCITT V.34 Voiceband Modem Standard), but two particularly convenient techniques are discussed later herein for two distinctly different modulation methods. However, the techniques for rate adaptation are easily extended to other modulation and coding schemes, and such extensions are considered part of the present invention.

Detailed Description Text - DETX (80):

Although a VRDSL connection is capable of certain transmission throughput, the total throughput might not be connected to corresponding CO backbone networks at times. For VRDSL-provided services going through the PSTN (Public Switched Telephone Network), connections will be made only when services are initiated. For VRDSL provided services terminated at the local CO, such as internet access, leased line or dial-up line connections with certain throughputs can be made depending on the preferred cost structure.

The available CO backbone throughput to each VRDSL modem can be different at different times. The subscriber-desired throughput could also vary for different applications .

Detailed Description Text - DETX (81):

With actual throughputs lower than that provided by the VRDSL physical transmission link, traffic concentration can be realized at CO backbone networks. Statistical multiplexing can also be realized by using a separate analog front end for each CO VRDSL modem. The required number of corresponding digital portions can be less than the number of analog front-ends, depending on the traffic behavior. In the extreme case, the digital portion of the CO VRDSL modem can be multiplexed among active VRDSL links by using the voice-band as a traffic indicating channel and keeping a copy of the digital state portion of the modem inside RAM.

Detailed Description Text - DETX (85):

A rate table is defined as a common syntax for the R and A signaling between layers. The rate table defines the rates that a particular layer can attempt to achieve. (In general, this will be defined by the hardware limitations of the modem.) During a rate request (R), an upper layer might signal a lower layer of a desire to change the rate structure. If the lower layer is able to reconfigure itself to a new set of operating parameters and achieve the requested rate, then it will do so and indicate this to the upper layer. If the lower layer determines the requested rate to be unacceptable, the upper layer is informed along with information about the rates that are available under the present operating conditions (A).

Detailed Description Text - DETX (91):

3. The Software Driver Layer 7310, 7410 views the connection as a virtual channel called the data link channel (DLC). For convenience, the DLC may be a frame structure that represents multiple N kbit/sec channels (N=16 or 64 e.g.). In addition, a control channel may be specified. This control channel may either be embedded in the lower layer channels or can be completely separated from the DSL connection. For example, the control signaling might be implemented in the voice-band via a V.34 modem connection.

Detailed Description Text - DETX (97):

Another straightforward method of varying the throughput is changing the bandwidth used in the transmission channel. By expanding the bandwidth, a greater number of symbols can be transmitted over the channel in a given interval. The symbol rate is roughly proportional to the bandwidth. However, the processing requirements

of the DSL modem also increase with the bandwidth; higher bandwidth requires greater computation for modulation/demodulation. The maximum usable bandwidth might either be restricted by channel conditions or modem hardware processing capability constraints.

Detailed Description Text - DETX (99):

Let the nominal serial transmission rate be R. Define the minimum rate step by which a DSL modem can change as dR. If the minimum rate is R-2*dR and the maximum rate is R+2*dR, then the set of achievable rates is given by [R-2*dR, R-dR, R, R+dR, R+2*dR]. For example, let R=300 kilo-symbols/second, and dR=100 kilo-symbols per second. The set of achievable rates become [100, 200, 300, 400, 500] kilo-symbols/second.

Detailed Description Text - DETX (100):

Let N represent the number of bits conveyed by each transmitted digital symbol. For example, a VRDSL modem might support operation with N in the set [2,3,4,5]. The higher values of N will convey more bits in a given period, but will also result in lower tolerance to noise.

Detailed Description Text - DETX (103):

Discrete multi-tone (DMT) modulation transmits low-rate data symbols over parallel subchannels. By splitting a high-rate serial data stream into multiple low-rate data streams that are transmitted in separate subchannels, the system can be tailored to better match a frequency selective channel. Good portions of the overall bandwidth (those subbands with high signal-to-noise ratio (SNR)) are used to transmit symbols with a larger number of bits/symbol. An unequal number of bits are assigned to different subehannels, depending on the available capacity of each subchannel. Essentially, the data can be distributed among subchannels in a manner allowing very efficient use of the overall bandwidth.

Detailed Description Text - DETX (104):

As with the high-rate serial data stream, the overall bandwidth of a DMT system can be increased or decreased according to the overall desired throughput, channel conditions, and modem hardware capabilities. Additionally, DMT modulation provides the capability of dropping or adding bandwidth a single subchannel at a time. For a DMT system with a large number of subehannels, this creates a very large selection of possible bandwidths. If desired, the number of subchannels can be varied while keeping the overall bandwidth fixed.

Detailed Description Text - DETX (114):

After the initialization of VRDSL, a control channel (for example, of 16 Kbps) has been allocated as an initial channel connection. This control channel will be reserved during the whole physical line connection time. It is used to send/receive all the control information including rate negotiation information.

Detailed Description Text - DETX (131):

Based on the VRDSL communication model, modem hardware capable of varying the transmission rate, and variable-rate management software, the rate negotiation method shown in FIG. 7f may be employed. FIG. 7f depicts a simplified functional diagram of the overall rate negotiation method.

Detailed Description Text - DETX (132):

Current QAM based voice-band modems make use of a handshake sequence between calling and answering modems to initialize their communications. To gain synchronization, the answering modem transmits alternating symbols of the corresponding constellation points. As an example, V.32 modems use the constellation points A,B,C, and D in FIG. 8a in the synchronization process. The answering modem transmits alternating symbols ABABAB . . . for a duration of 256 symbols. After 256 symbols, the alternating symbols CDCDCD . . . is transmitted for 16 symbols. The transition period between the two symbol sequences provides a well-defined event that may be used for generating a time reference in the calling modem receiver. After the second symbol sequence the answering modem will start transmitting a symbol sequence that is known by both modems. This sequence is used to train the equalizer at the calling modem receiver. FIG. 8a depicts a V.32 training constellation.

Detailed Description Text - DETX (133):

The frequency response of the voice-band channel (30 Hz to 3.3 KHz) is nominally flat. The alternating ABAB . . . and CDCD . . . symbols can be reliably detected before equalization of the channel. However, this is not the case for the MDSL modem. For a 1/14 T1, modems use the spectrum up to 500 KHz of the telephone line. FIG. 8b shows the frequency response of a telephone CSA loop 6. A startup procedure that allows for partial equalization of the line is required before timing synchronization is attempted.

Detailed Description Text - DETX (134):

A preferred embodiment uses a startup handshake procedure for the MDSL modem. It uses an algorithm for implementation of the receiver portion.

Detailed Description Text - DETX (137):

CO MODEM

Detailed Description Text - DETX (138):

1. The CO modem is assumed to be always "on", but in an idle state. It continuously transmits segment A and listens for segment D.

Detailed Description Text - DETX (139):

RU MODEM

Detailed Description Text - DETX (140):

1. The RU modem comes on line and starts listening for segment A from the CO modem.

Detailed Description Text - DETX (142):

CO MODEM

Detailed Description Text - DETX (143):

2. Once the CO modem detects segment D from the RU modem, it transmits segments B, C, and valid data without further handshaking from the RU modem.

Detailed Description Text - DETX (144):

RU MODEM

Detailed Description Text - DETX (145):

3. The RU modem listens for segment B and once detected, it transmits segments E, F, and valid data without further handshaking from the CO modem.

Detailed Description Text - DETX (146):

4. The detection of segment B is the critical timing instant in the synchronization procedure. After it is detected, the RU modem begins training its equalizer using data from segment C.

Detailed Description Text - DETX (147):

CO MODEM

Detailed Description Text - DETX (148):

3. The CO modem listens for segment E from the RU modem. The detection of segment E is the critical timing instant in the synchronization procedure. After it is detected, the CO modem begins training its equalizer using data from segment F.

Detailed Description Text - DETX (149):

The receiver makes use of cyclical equalization techniques to obtain initial timing synchronization. On startup, the RU modem sets up a fractional spaced adaptive equalizer that is equal in time duration to K symbol periods, for example, K may be 15. This will be called the sync equalizer. If the sync equalizer is operated at two times the symbol period, the number of taps required is 2.times.K. For four samples per symbol period, the number of taps required is 4.times.K, and so on.

Detailed Description Text - DETX (150):

The receiver uses the same K-symbol sequence as the transmitter for the training data of the sync equalizer. Because the length of the equalizer is a multiple of the symbol sequence length, the relative phase between the transmitted sequence and the receiver reference sequence does not matter.

Detailed Description Text - DETX (151):

Once the sync equalizer mean square error falls below a threshold, segment A has been detected. The receiver stops the adaptation process and analyzes the coefficients. It then rotates the coefficients in a circular manner so that the N consecutive coefficients with the most energy are grouped at the front of the sync equalizer filter. N is the length of the orthogonal adaptive filters used in CAP demodulation, (see the following paragraphs). This aligns the symbol period of the receiver with the symbol period of the transmitter.

Detailed Description Text - DETX (162):

Following the time domain equalizer training, the transmitter should send another sequence [y.sub.n] to train the frequency domain equalizer. The frequency domain equalizer training sequence can be made of exactly the repeatable block [y.sub.n]. FIG. 9d shows the entire training sequence. In the regime of training sequence [y.sub.n]pwr.sub.-- det remains high.

Detailed Description Text - DETX (170):

The SLSD mode works on a switched MDSL line on which the MDSL-R modem is dialed automatically by the MDSL-C which is controlled by a

remote server. Under this mode, the line management follows a special MDSL dial-up procedure that is independent from the Plain Old Telephone Service (POTS) line. The MDSL modem dial-up procedure is defined by the MDSL modem's internal initialization process. It has 2 dial-up IDs, one related to the MDSL-C port and the other related to the MDSL-R modem. The ID for MDSL-C port could be just the subscriber phone number plus 1 digit; by choosing it to be 0 and the ID for the MDSL-R modem could be the subscriber phone number also plus 1 digit selected to be 1. The other 8 values, from 2 to 9, are reserved.

Detailed Description Text - DETX (171):

The SLHD mode works in a way similar to that of voice-band modem but with MDSL dial-up procedure. The MDSL modem will either store a phone number or be dialed manually by an application.

Detailed Description Text - DETX (181):

The TxSpeed and RIxSpeed give the upstream and downstream line speed.

Detailed Description Text - DETX (310):

FIGS. 11a-b illustrates the software structure of the driver for modem 100 used with a host having a Windows 95 or Windows NT environment, as commonly would be the situation for a personal computer in a residence. FIG. 11c illustrates the software driver structure more generally.

Detailed Description Text - DETX (332):

The initialization entry point (MdslInitialize) will be called by NDIS library to initialize the MDSL modem.

Detailed Description Text - DETX (554):

The software to configure a multiinode modem as to its DSL band operation can be acquired by downloading into a Flash EPROM (see FIG. 5a of a board version of a DSL modem enhanced to include Flash EPROM). This downloading can be performed by using the voice-band configuration (V.34) already in the multimode modem. In particular, a host can use voice-band modem operation to call a source telephone number which then can download the software for DSL band operation over the voice-band to the Flash EPROM. In the same manner, updates of the DSL band software can be downloaded either over voice-band or over DSL band. FIG. 12 illustrates such a downloading process.

Detailed Description Text - DETX (555):

Referring now to FIG. 13a, there may be seen the MDSL frequency division for upstream and downstream. In voice-band modems, the highest frequency of interest is only 3.3 KHz. In MDSL, the highest frequency of interest can be hundreds of KHz. For example, for 1/4 T1 rates, the center frequency of the upstream channel F.sub.c1 is 100 KHz while the center frequency of the downstream channel F.sub.c2 is 300 KHz. The bandwidth of each channel is 200 KHz and the highest frequency of interest is F.sub.2+ =400 KHz. The challenge is to be able to process the data with a low cost programmable digital signal processor (DSP). This invention addresses how to reduce the processing requirements by making either passband signal depicted in FIG. 13a appear identical to the DSP.

Detailed Description Text - DETX (556):

The MDSL modem has two modes, the central office (CO) and remote user (RU) modes. In the CO mode, the modem transmits in the upper frequency band and receives in the lower frequency band. In the RU mode the reverse occurs. The modem transmits in the lower frequency band and receives in the upper frequency band.

Detailed Description Text - DETX (557):

Using the normal interpretation of the Nyquist Sampling Theorem, a minimum sampling rate twice the highest frequency of interest is required to process the data. For the CO modem, the analog-to-digital converter (ADC) can sample the received signal at twice F.sub.1+. However, it must generate samples for the digital-to-analog converter (DAC) at twice F.sub.2+. For the RU modem, the DAC can run at twice F.sub.1+. However, the ADC must run at twice F.sub.2+.

Detailed Description Text - DETX (558):

This invention makes use of digital sampling rate conversion to decrease the sampling rate and consequently the processing requirements for the implementation of the MDSL modem.

Detailed Description Text - DETX (559):

For the RU modem, the high sampling rate is connected with the analog-to-digital conversion process. The 1/4 T1 example modem receiver front end is shown in FIG. 13b at the RU modem. The incoming analog signal, centered at 300 KHz is first bandpass filtered to maximize the signal to noise ratio by isolating the bandwidth of interest. The signal is then sampled by the ADC at the normal Nyquist rate of twice f.sub.2+, 800 KHz.

Detailed Description Text - DETX (562):

For the CO modem, the high output sampling rate is required in the digital-to-analog process. It would require a minimum a sampling rate of 800 KHz to directly generate the output samples corresponding to the upper passband signal. It would be much better if the CO modem could generate the output samples in the lower frequency band, and somehow automatically translate the spectrum to the upper band. FIG. 13e shows the spectrum of the low band signal in the digital domain.

Detailed Description Text - DETX (563):

Translation can be accomplished by making use of the aliased images produced by digitally upsampling to a higher rate. Upsampling by two to 800 KHz consists of inserting a zero valued sample between the computed output samples. This generates images at harmonics of the original 400 KHz sampling frequency. When the new modified output data stream is passed to a DAC, the analog output spectrum shown in FIG. 13f is generated. (The sinc roll-off characteristic imparted by the conversion process has been left out of the figure). By the use of an appropriate analog bandpass filter, the inverted image centered at 300 KHz can be selected. Since the inserted values are zero, they need not be computed by the DSP. The inversion can be either corrected by multiplication of odd samples by (-1) or disregarded completely, since the spectrum is inverted again by the decimation process at the RU modem. As show in FIG. 13g, the zero sample interleaving process can be implemented by simple external logic outside the DSP.

Detailed Description Text - DETX (564):

In conclusion, the application of sampling rate conversion allows the DSP in the MDSL modem to assume that it is always transmitting and receiving only in the lower frequency band. Its computations are therefore based on a much lower sampling rate than would normally be dictated by the actual analog signal frequency content.

Detailed Description Text - DETX (570):

In the central office end, a modem pool can be used to handle multiple MDSL lines. Although a dedicated line coupling and front end circuit is necessary for each MDSL line, the signal processing power of a high performance DSP chip can be shared among multiple MDSL lines. The multiple line capability of an MDSL modem pool can be further enhanced by incorporating multiple DSP chips within a single modem pool unit.

Detailed Description Text - DETX (571):

FIG. 14 ashows that an MDSL modem pool can have N logical MDSL modems, each consisting of a transmitter part and a receiver part.

Due to the location of the modem pool, transmitters can be synchronized to the same central office clock. Because of the MDSL line concentration and the shared modem pool architecture, data symbols of the transmit signal and samples of the received signal are readily accessible among all logical modems. The transmit signal synchronization and the transmit and received signal accessibility enable the adaptation of NEXT cancellation technique. A multiple input-multiple output NEXT canceller can be implemented in conjunction with an MDSL modem pool.

Detailed Description Text - DETX (572):

To avoid the NEXT and the cost of echo cancellation hardware, a preferred MDSL modem uses frequency division duplex for transmission from a central office to a subscriber in the downstream direction and vice versa in the upstream direction. The downstream transmission normally occupies the higher frequency part of the MDSL spectrum. The frequency separation between the downstream and the upstream directions is based on the use of high order bandpass filters. FIG. 14b shows that a guardband is used between the upstream frequency band and the downstream frequency band spectrum. Furthermore, the bandwidth of each downstream spectrum can be different for different modems. This might be necessary because the spectral allocation could be optimized according to the individual line conditions and downstream to upstream throughput ratio.

Detailed Description Text - DETX (573):

Because of the finite amount of attenuation in the bandpass filter stopband and the closeness between downstream and upstream spectra, there will always be some residue noise from the reverse channel. Due to the heavy subscriber line attenuation, the relative strength of residual noise might not be negligible compared with that of the received signal. Because of the possibility of upstream and downstream spectra overlapping among different MDSL lines, the NEXT noise can occur within the region of guardband. Hence, the NEXT cancellation can be used to minimize the interference of reverse channel residual noise of the same MDSL line and the interference of reverse channel NEXT noise from adjacent MDSL lines.

Detailed Description Text - DETX (574):

FIG. 14c shows that a reverse channel NEXT canceller bank can be implemented within the same MDSL modem pool unit with or without additional DSP chips. The NEXT canceller bank needs the access to the transmit signal and the digitized received signal of all modems. The NEXT canceller bank has N NEXT cancellers as depicted in FIG. 14d corresponding to N MDSL modems. Each canceller has N adaptive filters of size M. Outputs of all N adaptive filters are appropriately combined to form the NEXT cancellation signal for the corresponding

modem. Each adaptive filter is adapted according to the error signal between the received signal and the NEXT cancellation signal and the corresponding transmit signal as the correlation vector as depicted in FIG. 14e.

Claims Text - CLTX (1):

1. A method for interfacing modem hardware with a host operating system comprising the steps of:

Claims Text - CLTX (6):

e) calling a defined set of host interface functions to use the voice-band as control channel and above voice-band for the data channel.

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